TETA TO-0017
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TEST EFFECTIVENESS TREND OBSERVATION

Correlation of Advancements in Spacecraft Digital Technology with EMC Test Failure Rate

CONCLUSIONS:

The increased failure rate in electromagnetic compatibility (EMC) testing correlates with the more extensive use of digital technology (as compared to analog) in the design of spacecraft electronic systems. The evolution of technology toward higher and higher packaging densities coupled with the lower operating voltages and reduced power of these sensitive logic devices result in a prediction of the continuation of this trend in increased test failures. Test programs and hardware development schedules will need to be ad usted accordingly to compensate for problem resolutions.

BACKGROUND:

Over the past 25 years seven ma or spacecraft have been built under JPL management. Four of these spacecraft were assembled at JPL and three were assembled by contractors. As these spacecraft were being developed, there was a ma or evolution in the miniaturization of electronic devices which resulted in the implementation of software controlled logic devices to accomplish tasks formerly handled by analog or mechanical systems. Figure 1 illustrates the exponential nature of the change in the numbers of equivalent transistors contrasted with a relatively slower growth in the number of piece parts over the same programs. While the number of piece parts increased by a factor of less than 10, the number of equivalent transistors increased a factor of 10^4! This proliferation of logic devices, with lower and lower operating thresholds and greatly reduced physical size, has brought with it increased concern over electromagnetic interference (EMI) issues.

DISCUSSION:

The ob ective of this analysis was to investigate what effects (if any) advances in electronic technology through the last three decades have had on spacecraft hardware EMI emissions and susceptibility. This analysis consisted in determining the number of problem failure reports (PFRs) which were initiated during the EMC testing of Mariner 6, Viking, Voyager, Galileo, Mars Observer, Magellan, and Topex/Poseidon. The PFRs were obtained for each of the following EMC tests: conducted emissions, conducted susceptibility, radiated emissions, radiated susceptibility, and grounding/isolation. Table 1 lists the total number of PFRs for each of the spacecraft as well as the launch year, the spacecraft dry mass, and the number of science instruments. It must be noted that these spacecraft vary widely in both size and complexity. Tables 2 through 8 show the test results in more detail. These tables are arranged in chronological order with the test results from the earliest pro ect occupying Table 2 and the results from the most recent pro ect occupying Table 8. These tables provide the number of PFRs for each EMC test on each spacecraft and the listed cause for each PFR.

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Table 1. Total Number of EMC Test PFRS

SPACECRAFT	YEAR OF LAUNCH	DRY MASS (kgms)	NO. OF SCIENCE INSTR.	NUMBER OF EMC PFRS
Mariner 6	1969	412	5	6
Viking	1975	903	3 (+Lander)	35
Voyager	1977	825	11	58
Galileo	1989	1736	11 (+ Probe)	134
Magellan	1989	1152	1	22
Mars Observer	1989	1047	7	36
Topex/Poseidon	1989	2180	6	50

As shown in Table 1, in the 1960's when the Mariner 6 spacecraft was built there were only 6 PFRs recorded during EMC testing. The number of PFRs increased to 35 when the Viking spacecraft was built in the early 1970's. The number of EMC related PFRs increased when the Voyager spacecraft was built in the mid 1970's. Part of the increase on Voyager was due to the fact that Voyager was a larger and more complex spacecraft than Viking and more EMC testing was done at the assembly level; hence, more tests were performed on Voyager compared to Viking. For Galileo the number of PFRs doubled when compared to Voyager. Galileo was built in the early 1980's and considerably more testing was done on Galileo than on Voyager because of design changes imposed by delays, changes in launch vehicle configuration (ELV to STS), and the Challenger accident (Centaur to IUS).

In the mid and late 1980's three new spacecraft were built: Mars Observer, Magellan, and Topex (Tables 6 through 8). These spacecrafts were designed, assembled, and tested by system contractors. Table 1 suggests that the number of reported EMC testing PFRs generated by systems contractors were fewer than on Voyager and Galileo. This is due in part to differences in the implementation of PFRs for in-house and contractor built spacecraft. It should be noted that Reference 1 has shown that the overall trend in environmentally related PFRs is toward a higher incidence of test anomalies with system contractor provided hardware. Nevertheless, the nature of the EMC related PFRs reported in both modes still supports the relationship of higher failure rates with increased complexity in spacecraft electronics.

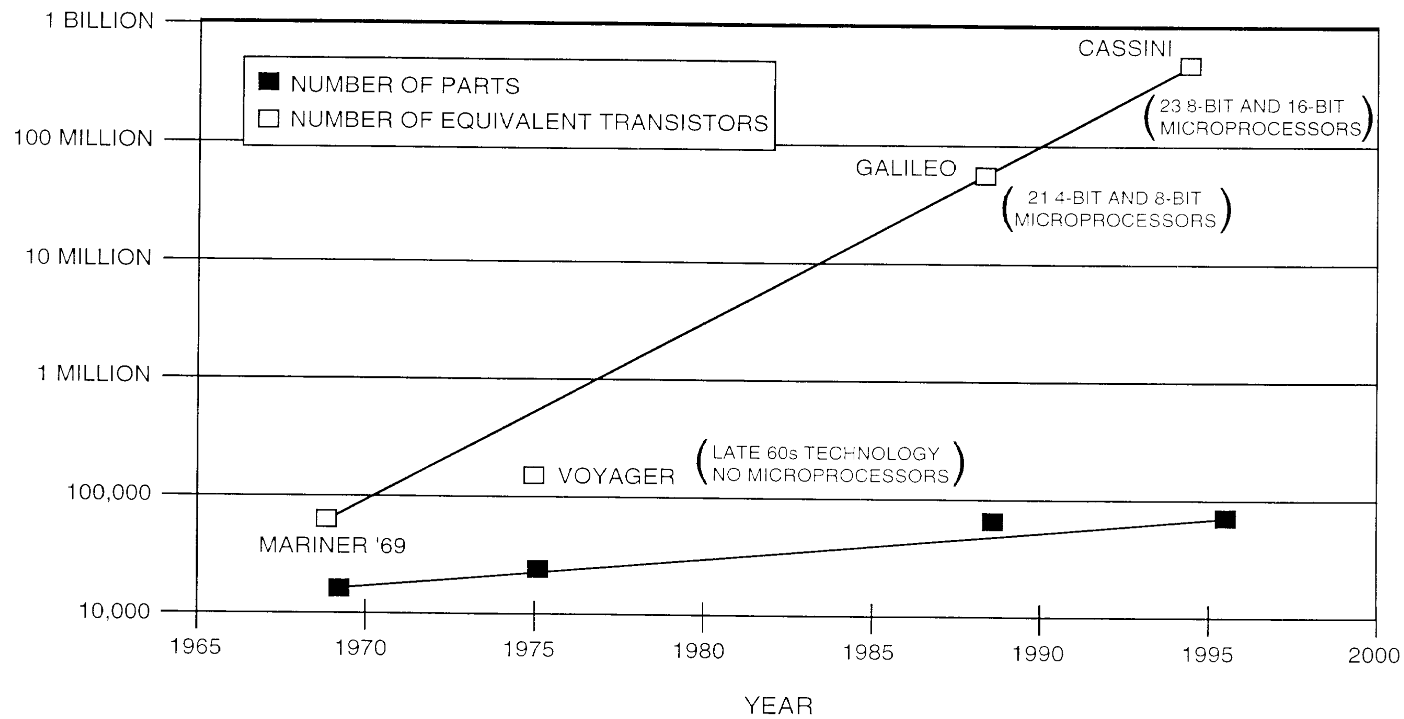

Figure 1. Increase in Spacecraft Electronic Complexity

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At a more detailed level, the results in Tables 2 through 8 indicate that the largest increase in PFRs occurred during conducted and radiated emissions tests. Though increased PFRs were also recorded for conducted and radiated susceptibility the increase was not as dramatic as for emissions. For example comparing the results of Tables 2 and 5 (Mariner 6 vs Galileo) the number of conducted emissions PFRs increased from 1 to 38 while radiated emissions PFRs increased from 1 to 62. Conducted susceptibility PFRs went from 0 to 9 and radiated susceptibility PFRs increased from 3 to 16. As noted in Reference 2, the number of PFRs resulting from EMI related to grounding is significant and this summary indicates that grounding continues to be a problem area even during system level testing.

In reviewing the test results that caused the initiation of the PFRs, conducted and radiated emissions specification requirement violations were the main cause for PFRs. The pattern of EMI recorded during the tests, exceedences in the 10 to 200 Mhz region, indicates that much of the noise came from digital circuitry.

Based on these results, the trend is for EMC testing anomalies to increase as the use of digital technology increases and as higher packing densities in VLSI chips are achieved.

Table 2. PFR Statistics for Electromagnetic Compatibility Tests

Spacecraft Mission: Mariner 6

EMC TEST	Number of EMC PFRs	Rationale(s) for PFR
Conducted Emissions	1	Emission measurements above spec. limits
Conducted Susceptibility	0	
Radiated Emissions	1	Emission measurements above spec. limits
Radiated Susceptibility	3	Hardware susceptible to field levels at several frequencies
Isolation & Grounding	0	

Table 3. PFR Statistics for Electromagnetic Compatibility Tests

Spacecraft Mission: Viking

EMC TEST	Number of EMC PFRs	Rationale(s) for PFR
Conducted Emissions	1	Emission measurements above spec. limits
Conducted Susceptibility	3	Hardware susceptible to field levels at several frequencies
Radiated Emissions	4	Emission measurements above spec. limits
Radiated Susceptibility	7	Hardware susceptible to field levels at several frequencies
Isolation & Grounding	20	a) shorted circuits, b) chassis not well grounded, c) isolation less than required by specs.

Table 4. PFR Statistics for Electromagnetic Compatibility Tests

Spacecraft Mission: Voyager

EMC TEST	Number of EMC PFRs	Rationale(s) for PFR
Conducted Emissions	14	Emission measurements above spec. limits
Conducted Susceptibility	6	Hardware susceptible to field levels at several frequencies
Radiated Emissions	18	Emission measurements above spec. limits
Radiated Susceptibility	10	Hardware susceptible to field levels at several frequencies
Isolation & Grounding	10	a) shorted circuits, b) chassis not well grounded, c) isolation less than required by specs.

Table 5. PFR Statistics for Electromagnetic Compatibility Tests

Spacecraft Mission: Galileo

EMC TEST	Number of EMC PFRs	Rationale(s) for PFR
Conducted Emissions	38	Emission measurements above spec. limits
Conducted Susceptibility	9	Hardware susceptible to field levels at several frequencies
Radiated Emissions	62	Emission measurements above spec. limits
Radiated Susceptibility	16	Hardware susceptible to field levels at several frequencies
Isolation & Grounding	9	a) shorted circuits, b) chassis not well grounded, c) isolation less than required by specs.

Table 6. PFR Statistics for Electromagnetic Compatibility Tests

Spacecraft Mission: Magellan

EMC TEST	Number of EMC PFRs	Rationale(s) for PFR
Conducted Emissions	13	Emission measurements above spec. limits
Conducted Susceptibility	0	
Radiated Emissions	6	Emission measurements above spec. limits
Radiated Susceptibility	3	Hardware susceptible to field levels at several frequencies
Isolation & Grounding	0	

Table 7. PFR Statistics for Electromagnetic Compatibility Tests

Spacecraft Mission: Mars Observer

EMC TEST	Number of EMC PFRs	Rationale(s) for PFR
Conducted Emissions	9	Emission measurements above spec. limits
Conducted Susceptibility	4	Hardware susceptible to field levels at several frequencies
Radiated Emissions	14	Emission measurements above spec. limits
Radiated Susceptibility	8	Hardware susceptible to field levels at several frequencies
Isolation & Grounding	1	a) shorted circuits, b) chassis not well grounded, c) isolation less than required by specs.

Table 8. PFR Statistics for Electromagnetic Compatibility Tests

Spacecraft Mission: Topex/Poseidon

EMC TEST	Number of EMC PFRs	Rationale(s) for PFR
Conducted Emissions	14	Emission measurements above spec. limits
Conducted Susceptibility	9	Hardware susceptible to field levels at several frequencies
Radiated Emissions	18	Emission measurements above spec. limits
Radiated Susceptibility	7	Hardware susceptible to field levels at several frequencies
Isolation & Grounding	2	a) shorted circuits, b) chassis not well grounded, c) isolation less than required by specs.

References:

1. TETA TO-0014. Problem/Failure History vs. Origin of Flight Hardware, by C. Gonzalez

2. TETA TO-0012. Assessment of EMI Grounding Problems Encountered in Flight Hardware Prior to System Level EMC tests, by R. Perez

APPENDIX

The ma or classes of EMC testing are described below.

Conducted Emissions: The intent of the conducted emission requirements is to restrict the DC noise current passing out through the spacecraft assemblies' power/signal cables. The reason for this is that these noise currents cause noise voltages on the common power/data bus of the spacecraft and can affect other systems and instruments which feed from the same power/data bus (conducted EMI).

Radiated Emissions: The intent of the radiated emissions requirements is to restrict the unintentional radiated levels of electric and magnetic fields that are produced by any spacecraft system, subsystem, or instrument. The rationale for this is that these emissions can interfere with the spectrum of many receiver circuits or disrupt other sensitive circuitry.

Conducted Susceptibility: The intent of the conducted susceptibility requirements is to verify that noise entering power and signal cables will not interfere with the normal operating conditions of spacecraft systems.

Radiated Susceptibility: The intent of the radiated susceptibility requirements is to ensure that the spacecraft system, subsystem, and instrument will operate properly in an environment where intentional and unintentional radiators of electromagnetic energy are present.

Grounding/Isolation: The intent of the grounding and isolation is to verify that power circuits are DC isolated from chassis ground or circuit common according to given specification requirements. Generally, the requirements involve grounding the circuitry of all spacecraft systems to a single point (single point grounding) in order to avoid EMI grounding problems such as: a) ground loops, b) common impedance coupling.